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Local practices for production of rice husk biochar and coconut shell biochar: Production methods, product characteristics, nutrient and field water holding capacity

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Abstract
Application of biochar is widely reported to enhance soil quality and decrease leaching of nutrients. In this study, biochar from rice husk and coconut shells were used to determine physico-chemical characteristics, ability on nutrients and water holding capacity in soil. These biochars were produced using conventional processes of rotary husk (for rice husk) and kiln-drum furnaces (for coconut shells). It was found that coconut shell biochar (CSB) was very effective in retaining nitrogen compared to rice husk biochar (RHB). Leaching analysis over 19 days (100 ml each day) has identified 15 g/kg of CSB in Bungor series soil to consistently maintain a leaching rate of nitrogen at below 5 mg/litre as compared to other samples. Meanwhile, RHB was very effective in retaining water compared to CSB with highest water retention at 31.2%. Overall results indicate that conventionally made biochar has great potential to reduce nutrient leaching and improve water holding capacity in soil. CSB is more effective in reducing nutrient leaching, particularly nitrogen while RHB was most effective in increasing field water holding capacity. Further research is required to study its effectiveness on nutrient plant uptake.

Keywords: biochar, nutrient leaching, nitrogen, potassium, field water holding capacity

Introduction

Biochar is a solid carbon-rich product produced when biomass such as stalks, straw, wood and leaves is heated in a closed container without or limited presence of air. It is added to soil to improve the fertility and plant growth.

Conversion of organic materials to biochar through pyrolysis will provide an alternative to manage a range of agricultural wastes. In Malaysia, sources of biomass such as rice husk and coconut shells are considered abundant (Wan Ab Karim Ghani 2010). Therefore, effective measures need to

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be taken to manage these wastes effectively. Thus, biochar is currently one of the potential options.

Various production methods for biochar exist, including batch type (slow) pyrolysers and continuous type (fast) pyrolysers. Among these, the popular technologies include mould kiln, drum type pyrolysers, screw type pyrolysers and rotary kilns (Duku et al. 2011). Currently, effective use of biochar in agriculture has been relatively new in Malaysia. However, conventional industry for making biochar basically existed for years. Production of biochar is actually quite similar to production of charcoal which is one of the most prominent ancient technologies (Lehmann and Joseph 2009). Basically, charcoal and biochar only differ in terms of its practical application (Tenenbaum 2009). Charcoal is used primarily as fuel while biochar has nonfuel use that includes its application for agriculture.

In Tanjung Karang, a granary area in Selangor, a system for making biochar known as Rotary Husk Furnace (RHF) has been popular. This is due to the biochar product which has been widely used as media for rice transplanting seedlings. RHF is based on continuous processes of fast pyrolysis. It also gives higher biochar yields as compared to batch processes (slow pyrolysis). Thus, the system provides the farmers with benefit of lesser time for production (few minutes) as compared to batch processes (few hours). Study by Haefele et al. (2009) has proposed charring of residues in an incomplete combustion process which produces biochar as an efficient option for rice residue management. The charred material subsequently can be incorporated into paddy soils and used as soil conditioner. A study on a local producer in Tanjung Karang area has estimated annual production of 81.43 tonnes of RHB for use as media for rice transplanting seedlings (Mohammad Hariz et al. 2010).

At places like Hilir Perak, charring of coconut shells was conducted in slow pyrolysis that would take approximately 6 – 8 h. Conventional technique of slow pyrolysis involves production of biochar and white smoke (Gustafsson 2013). The products can be used for many purposes. Additionally, the smoke can also be refined for agricultural use (Mungkunkamchao 2013). Previously, conventional farmers condensed the smoke from charring process (such as mangrove charring in Kuala Sepetang) to produce additional by-products known as ‘cuka arang’. ‘Cuka arang’ is basically a form of acids (wood vinegar) which contain beneficial effects on crops as insect repellant (Mohan et al. 2006).

Biochar is being considered as a soil conditioner rather than fertiliser due to low nutrient contents. Therefore, it is most effective when used in combination with other chemicals, such as synthetic fertiliser (Steiner et al. 2007). Enhanced nutrient retention of soils added with biochar reduces the total fertiliser requirements and environmental effects associated with fertilisers (Yeboah et al. 2009). Therefore, biochar can be important to crops, depending on the micro and macro environment conditions that support its applications.

Similar to nutrient holding capacity, water holding capacity is also an important parameter that measures the ability of biochar to retain water by adhesion and cohesion forces (Song and Guo 2011). Research has demonstrated that highly porous nature of biochar can act as sponges to modify soil textures. This subsequently increases the soil water holding capacities.

This research has two objectives. The first objective was to identify the characteristics of two conventionally produced biochar mostly used by smallholder farmers. The second objective was to determine the nutrient and water holding capacity of each biochar. This can ultimately help towards the effective utilisation of biochar in agriculture.

Materials and methods

Rice husk biochar (RHB) was obtained from Tanjung Karang, Selangor. It was produced by a local farmer using rotary-husk furnace (RHF) method. Under this technique, raw materials of rice husks were burned in short period (less than 10 s) in a rotary chamber using continuous process. Meanwhile, coconut shell biochar (CSB) was produced using method applied by the farmers in Hilir Perak, Perak. The system was replicated in integrated organic farm, MARDI Serdang. For charring process, the shells were pyrolised in a drum-kiln using a fed-batch process for 5 h. All production methods were observed, and diagrams on the model of production were sketched using AutoCad 2012. Prior to analysis and the experiment, CSB was crushed to small partile size <0.5 cm. All biochars were sealed and stored under room temperature.

The elemental C and N, were determined using C, N, S elemental analyser (Vario El III) while P, K, Ca, Mg and Na using acid digestion (Campbell and Plank 1992) followed by the use of Inductively Coupled Plasmas-Atomic Emission Spectrometer (ICP-AES, Perkin Elmer). Cation exchange capacity (CEC) was analysed using Barium acetate method (Harada and Inoko 1980). The pH was measured using pH electrode while conductivity (EC) using a conductivity meter at ratio sample:water at 1:10. Ash content (AOAC 1995) was determined by ignition of known weight of samples at 600 °C until all carbon is removed. The final calculation is based on the percentage of ash from the original compound. Meanwhile, analysis on the structure using Scanning Electron Micrograph (SEM) was carried out using Fei Quanta 400 ESEM. BET surface area was determined using Micromeritics ASAPTM 2020 outsourced to Nottingham MyResearch Sdn. Bhd. For biochar composition, the percentage was calculated according to the method by Zanzi et al. (1996):

$$\text{Biochar yield (wt.\% daf)} = \frac{(A_b/A_c) - (A_b/100)}{1 - (A_b/100)} \times 100$$

where A_b is wt.% ash in dry biomass and A_c is wt.% ash in dry biochar.

Trial for nutrient leaching capacity was conducted using Bungor series soil with different rate of biochar at 0, 5, 10 and 15 g/kg (w/w). The experimental study was carried out using mixture of soil: biochar of CSB and RHB in PVC column (6 cm diameter x 50 cm height). One gram of fertiliser (obtained and packed by Mibamansura Trading Sdn. Bhd.) was added on top of each soil:biochar mix. For each sample, the leaching involved 1,900 ml equivalent of leached water. A volume of 100 ml of water was added to the soil:biochar mix in the column from top to bottom everyday for 19 days. Leachate (at the bottom) was collected for analysis at every 300 ml. However, it was collected at 400 ml on the first sample collection. Overall, leachate analysis was done in five stages. For analysis, leachate samples (50 ml) were filtered (<0.45 µm nylon filter), and analysed for total N. For K value, samples were analysed using ICP-AES according to method by Laird et al. (2010).

Similarly, field water holding capacity was also carried out using combination of different rate of biochar at 0, 5, 10 and 15 g/kg with Bungor series soil. Field water holding was measured using method provided by MASS (2010) and Dugan (2010). Fresh sample (20 g) was sealed in mesh type cloth to be saturated in water for 6 h. Subsequently, the sample was drained overnight at room temperature (sample will be hanged with sufficient space below for water to drain from the sample). At this stage, the sample is considered near its maximum water retention capacity. The weight of water content in soil was determined. The water content retained in the soil is described as field water holding capacity.

Statistical analysis

Soil samples were mixed up thoroughly prior to the experiment on nutrient and field water holding capacity. All experimental runs were conducted in triplicate and the results were expressed as the mean values. For analysis on statistics, the data were analysed using Least Significant Difference (LSD) Test using SAS version 9.3 software package.

Results and discussion

Production methods

In the production of RHB, the system of RHF is quite similar to rotary kilns. It comprises an inlet (feeder) and outlet which operates in a continuous process (*Figure 1a*). The only difference is that RHF applies the concept of self-combustion without an efficient control of oxygen inside the furnace. However, the process needs a starter for ignition for the combustion to begin. Once ignited, it will continue burning the feeds (rice husk) through self-combustion until the source depleted. There is a water sprinkler at the outlet to cool the charred rice husk. The springkling ensures that the husk form biochar instead of complete burning compound such as ash.

Meanwhile, the production of CSB involved a fed-batch process in which the feed (raw coconut shells) was added to a pyrolysis system comprising a drum size kiln (*Figure 1b*). A starter ignited the feed for initial combustion. The process eventually sustain by itself through self charring. Initial volume (size) of feed was reduced to half of its original composition after 2 h (due to charring process). Following this, a new batch will be added to the system to continue with the process. The charring normally continues for 5 h until the biochar in the kiln reaches the maximum volume.

For coconut shells, the charred material are usually used for the production of activated carbon. Normally, the shells are converted to charcoal by conventional farmers. It was eventually further processed into activated carbon in large factories. In Malaysia, this scenario can be seen at Hilir Perak, Perak. In terms of market value, the trade balance for export in activated carbon products in 2007 was estimated at RM40 million (Sivapragasam 2008). Charring process for CSB followed the same procedure as charcoal. However, the material was directly used as media for agricultural practice instead for industrial use.

Characteristics of biochar

Comparisons were made between the raw materials and biochar. The coconut shells has higher percentage of carbon as compared to rice husk (*Table 1*). Previous study by Wan Ab Karim Ghani et al. (2010) identified the same characteristics. Meanwhile, it was observed that amount of N of both samples increased after charring process.

Table 2 shows the difference in physical characteristics between RHB and CSB. The biochars were different in terms

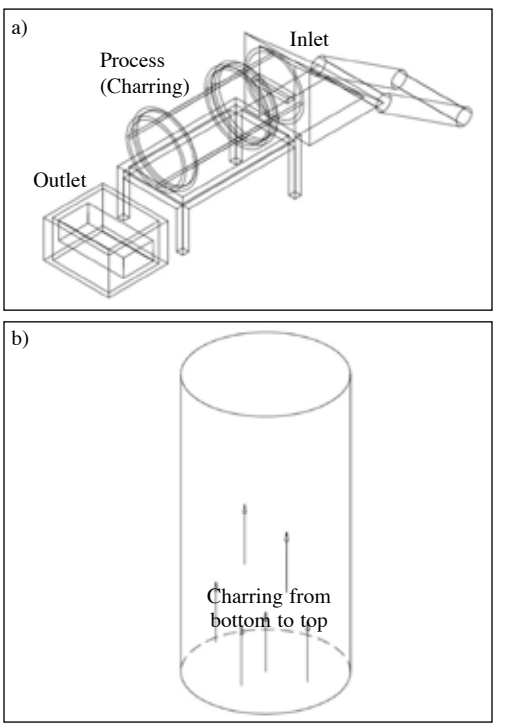

Figure 1. Schematic diagrams of the production concept for (a) RHB using RHF (fast pyrolyis) and (b) CSB using drum-kiln (slow pyrolysis)

Table 1. Chemical characteristics of rice husk, coconut shells, RHB and CSB

Sample type	% of dry matter						PPM
	C	N	P	K	Ca	Mg	Na
Rice husk (raw)	36.80 ± 1.80	0.47 ± 0.02	0.04 ± 0.01	0.18 ± 0.01	0.57 ± 0.01	0.03 ± 0.01	44.19 ± 3.99
Coconut shells (raw)	48.47 ± 0.25	0.12 ± 0.04	0.01 ± 0.00	0.17 ± 0.02	0.02 ± 0.00	0.01 ± 0.00	200.39 ± 21.15
Rice husk biochar (RHB)	39.53 ± 1.79	0.68 ± 0.06	0.18 ± 0.01	0.56 ± 0.04	0.09 ± 0.01	0.09 ± 0.01	70.53 ± 3.12
Coconut shell biochar (CSB)	41.76 ± 8.60	0.38 ± 0.04	0.10 ± 0.03	0.76 ± 0.06	0.10 ± 0.02	0.07 ± 0.02	3371.81 ± 605.45

Table 2. Comparison of the physical characteristics of RHB and CSB

Type of biochar	Moisture (%)	Ash composition (%)	Biochar yield (%)	CEC (cmol/kg)	BET surface area (m^2/g)	pH	EC (uS)	Major particle sizes (%)
Coconut shell biochar (CSB)	7.0 ± 0.0	18.3 ± 0.4	30.1 ± 0.9	5.1 ± 0.2	301.1 ± 11.6	9.3 ± 0.6	235.4 ± 129.9	> 10 cm (coconut shell shape)
Rice husk biochar (RHB)	28.2 ± 0.5	36.8 ± 1.5	32.3 ± 2.1	18.3 ± 5.8	94.7 ± 10.5	7.0 ± 0.0	719.0 ± 42.5	60.2% (0.6 – 1.7 mm)

of the biochar's ash composition. However, characterisation shows that percentage of biochar yield is quite similar between CSB (30%) and RHB (32%). Generally, carbon percentage was not much reduced when the materials were converted into biochar. Lehmann et al. (2006) found that through conversion of biomass to biochar, about 50% of the initial carbon may be retained (from reductions in total weight), compared with the low amount retained after complete burning (3%) and natural decomposition (less than 10 – 20% after 5 – 20 years), depending on the type of biomass used. In this study, there were slight increases in carbon when compared to the initial composition (per weight basis). However, when calculated at losses from initial weight, total carbon may reduce at about half of its initial value.

CEC for CSB and RHB was 5.3 cmol(+)/kg and 18.9 cmol(+)/kg respectively. Study by Sukartono et al. (2011) obtained slightly higher value for CEC and CSB. However, CEC of RHB is quite similar when compared to the study by Theeba et al. (2012). CEC refers to the quantity of the negative charges on the surface of the organic matter (Camberato 2001). The negative charge will attract positively charge ions, such as K, Mg and Ca in the soil. Higher CEC in a compound means it has better capacity to bind and retain certain nutrients.

Other additional factors may also contribute to the improved characteristics of biochar. A closer view of the Scanning Electron Micrograph (SEM) in *Figure 2* shows that RHB has more spongy type of the surface as compared to CSB. However, CSB possesses smaller pores on its surface than RHB when SEM was viewed at 1000x magnification. This characteristic was not observed on the surface of RHB. Meanwhile, surface area for CSB was higher compared to RHB (*Table 2*). It is possible that these characteristics contributed to the difference in nutrient and water holding

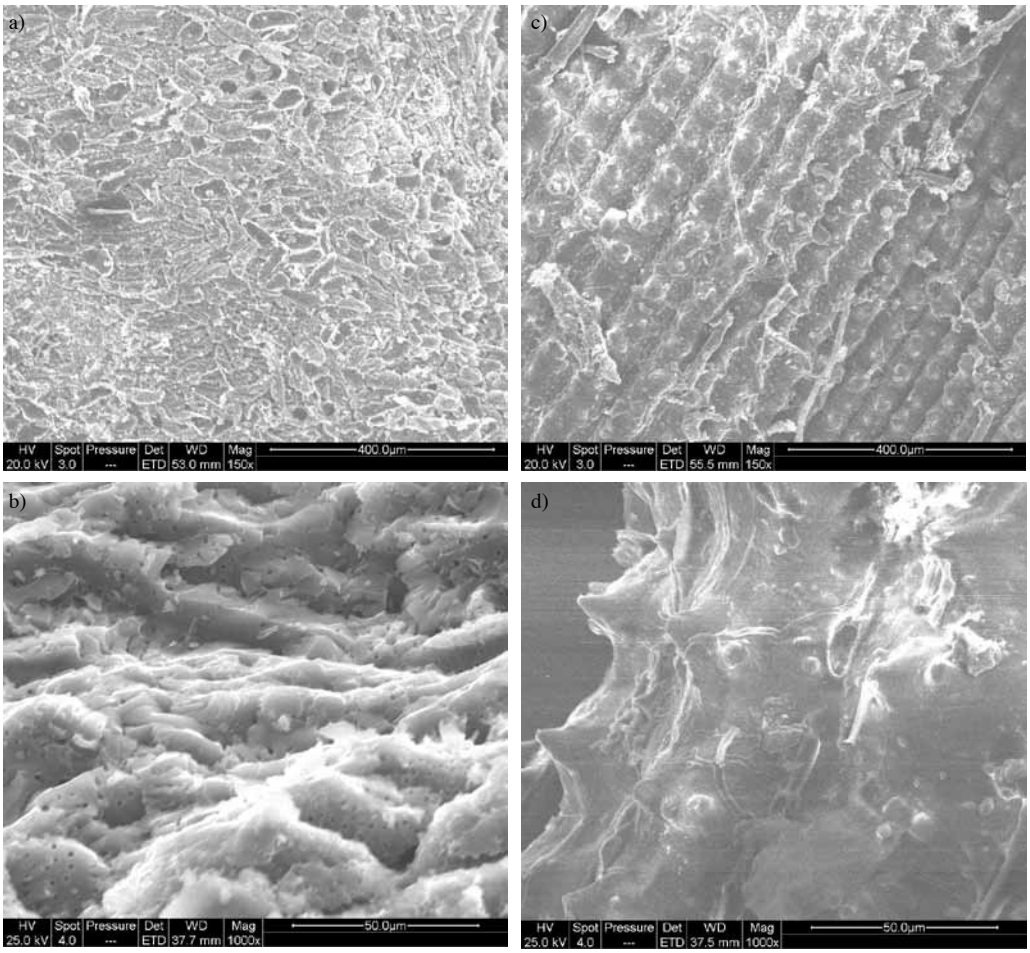

Figure 2. Scanning electron micrograph (SEM) of CSB for (a – b) and RHB for (c – d) at 150x magnification (upper row) and 1000x magnification (lower row). Note the presence of significantly small pores on the surface of CSB at 1000x magnification (b)

capacity of the compounds. It will be further discussed in the following subsections.

Soil and fertiliser characteristics

Prior to the experiments, the nutrient content of soil and fertiliser were evaluated. The nutrient contents of the soil for organic carbon was 0.30% ± 0.01, nitrogen 0.13% ± 0.00, phosphorus 92.03 ppm ± 5.95, boron 0.81 ppm ± 0.03, potassium 0.12 cmol(+)/kg ± 0.10, calcium 0.44 cmol(+)/kg ± 0.05, magnesium 0.06 cmol(+)/kg ± 0.02, and sodium 0.01 cmol(+)/kg ± 0.00. The CEC of the soil was 7.16 cmol(+)/kg ± 1.07. Meanwhile, the fertiliser content for N was 10.21% ± 0.23 and K_2O 16.61% ± 1.13.

Nitrogen (N) holding capacity of biochar

Figure 3a describes the trend in N concentration in all samples for RHB. There were reductions in terms of the amount of N in leached samples as compared to the control (soil). It can be seen that leaching of N was high between day 5 and day 10. Application of 15 g/kg of RHB reduces N leaching most effectively as compared to the 5 g/kg and 10 g/kg of RHB. Overall, 15 g/kg of RHB reduced leaching by 25.6% compared to control.

Leaching trend for control was highest on day 7, before gradually reduced on day 10, 13, 16 and 19. The trend is also quite similar for 5 g/kg of RHB. Initially, on day 4, there was no leaching of N measured from the leachate samples for 10 g/kg and 15 g/kg of RHB as compared to 1.3 mg/litre respectively for soil and 5 g/kg RHB. On day 7, leaching occurred with concentration of 11.2 mg/litre and 12.2 mg/litre for 10 g/kg and 15 g/kg of RHB respectively. Highest leaching was achieved at day 10 for 10 g/kg and 15 g/kg of RHB, but still lower than that of control.

Similarly, N leaching was also reduced with addition of CSB (*Figure 3b*). In fact, leaching reduction was more effective with CSB as compared to RHB in terms of the reduced leachate concentration. As for comparison, application of 15 g/kg of CSB yielded constant N concentration reduction to 5 mg/litre as compared to variation between 10 mg/litre and 15 mg/litre of N for RHB.

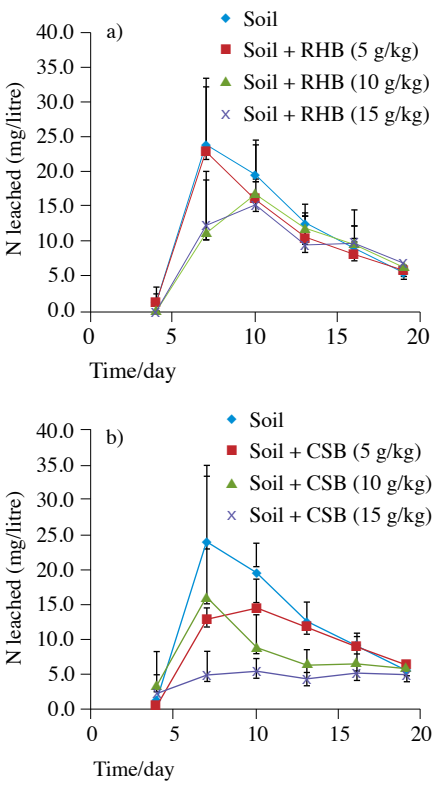

Figure 3. Leaching of N from soil columns amended with RHB for (a) and CSB for (b). The samples were leached daily with 100 ml deionised water for 19 days. Significantly different compared to control (soil) at p <0.05*

Application of 15 g/kg of CSB reduces leaching significantly compared to 5 g/kg and 10 g/kg. The concentration was below 5 mg/litre for the whole 19 days. Application of 15 g/kg of CSB has been the best in terms of rate to reduce N leaching in this study. Overall comparison showed 15 g/kg of CSB reduced leaching by 62.8% compared to control.

Similar trend of N leaching was also found in the study by Hyland et al. (2010) and Knowles et al. (2011). Biochar generally contains high C:N ratio which makes it a substance that can improve soil quality. Biochar decreases the mineralisation of N in the soils (Demspter et al. 2012). Besides, it can also prevent or limit the anaerobic production of nitrous oxide, another form of N losses in the environment (Winsley 2007).

In terms of CEC, a soil mixture with high CEC will leach NO_3 more readily than any other compounds (McClellan 2012). In the soil, N usually exist in the form of NO_3, an anion (negatively charge) that can readily leach through the soil profile. Less negatively charged particles in soil could possibly reduce the repellence effects of the negatively charged NO_3, thus reducing leaching. A compound with high CEC means it has more negatively charge particles, suggesting not a very good candidate to retain NO_3 in soil, although it may good for other nutrients. This theory could support the reason why leaching in RHB (CEC of 18.9 cmol(+)/kg) was higher as compared to CSB (CEC of 5.3 cmol(+)/kg). Therefore, optimum leaching reduction can thus be achieved with utilisation of CSB.

Additionally, observation from *Figure 2* may also explain why CSB is better from RHB in terms of retaining nutrient from N leaching. The presence of small pores on the surface of CSB may act as the binding site for N, thus increasing its

capacity to retain N. In contrast, there were no visible pores observed on the surface of RHB at 1000x magnification of SEM. Also, surface area of CSB (301.1 m^2/g) was higher than that of RHB (94.7 m^2/g). Study by Li et al. (2010) and Bekele et al. (2014) suggested surface area as one of the contributing factors that increased ionic sorption of material.

Potassium (K) holding capacity of biochar

The application of biochar increased the amount of leached K from the soil (*Figure 4*). This seems to be different to the trend of N where increasing amount of biochar reduces the nutrient N concentration in leachate. In fact, the increased concentration of K in the leachate of biochar samples (CSB and RHB) was higher than the control samples. The trends were seen during the whole 19 days. Similar trend was also observed in the study by Atland and Locke (2012) where additions of biochar increased K leaching.

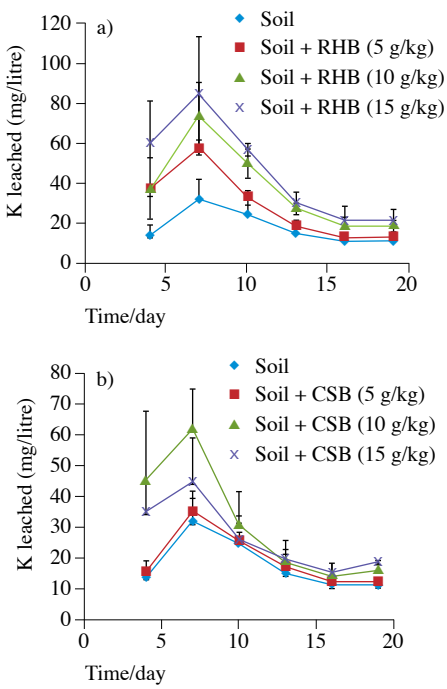

*Figure 4. Leaching of K from soil columns amended with rice husk biochar (RHB) for (a) and coconut shells biochar (CSB) for (b). The samples were leached daily with 100 ml deionised water for 19 days. * Significantly different compared to Control (soil) at p <0.05*

Highest amount of K was collected at day 7 (for both RHB and CSB). Eventually, leaching concentration was reduced as sampling reached 19 days. The observation for RHB showed that highest leaching was achieved at aplication rate of 15 g/kg RHB. However, for CSB, it was the the rate of 10 g/kg of biochar that gives the highest result. In comparison between RHB and CSB, highest concentration for K (in day 7) in the leachate was measured at 84.72 mg/litre for RHB while for CSB, it was measured at 61.99 mg/litre.

Lehmann et al. (2003) found that K in leachate has increased after the addition of biochar to soil, which attributed to the high K content of the biochar itself. This demonstrates that nutrient K within the biochar was at least partly mobile. It could be the reason why eventually there is quite high concentration of K in the leachate. Further study needs to be done, at least to differentiate between K contents in the fertiliser as well as the K contents from the biochar. In the long term, studies need to be carried out to determine whether the leached K is similar to the amount taken up by the plants. However, in terms of general concentrations, basically additions of biochar increase the K concentration in the leachate.

Field water holding capacity of rice husk biochar (RHB) and coconut shells biochar (CSB)

For RHB, increasing the application rate from 5 – 15 g/kg increased the water holding capacity (WHC). The increment rate was calculated at 0.8% (5 g/kg), 1.6% (10 g/kg) and 3.0% (15 g/kg) compared to control. The increment was consistent, suggesting potential use to improve WHC in soil. Overall, highest WHC of RHB was at 31.2% (15 g/kg) compared to 28.16% for control.

Meanwhile, this study found that overall WHC for CSB was slightly low from the control (soil). This result is totally different to RHB which showed higher

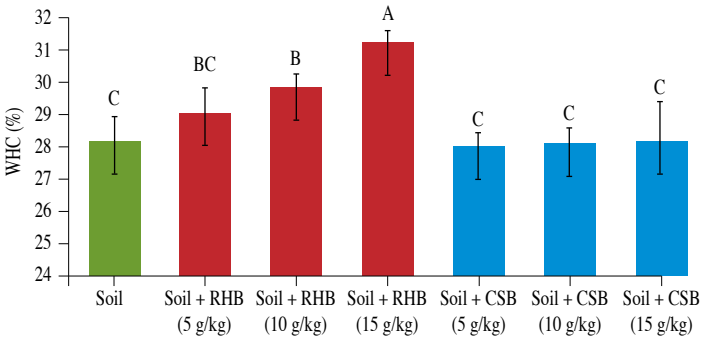

Figure 5. Water holding capacity (WHC) of soils amended with rice husk biochar (RHB) and coconut shell biochar (CSB) at three different rates (5,10,15 g/kg); bars with the same letter are not significantly different at $p < 0.05$

results from the control samples. Statistical analysis identified non-significant response with addition of CSB (*Figure 5*).

WHC was not improved partly due to the material characteristics of CSB itself. CSB has higher material density as compared to the RHB. This relationship can be explained from the volume of water that a material may hold. Higher density usually related to compacted material with reduced volume and capacity to absorb water.

There could also be several other reasons for the increased in water holding capacity for RHB. Rice husk basically is high in silica (Kalapathy et al. 2000). This makes the compound more capable to hold water in the soil. Silica based materials which was modified have shown to have better performance to absorb water (Rungrodnimitchai et al. 2009)

Conclusion

Conventional production of biochar in Malaysia has been quite popular. It was being popularised by smallholder farmers using a very simple technique for production. Rice husk biochar and coconut shell biochar are two types of biochar which have been widely produced and used in agriculture as well as for industries. In terms of the characteristics, each may represent different attributes. Coconut shell biochar is more effective to reduce nutrient leaching (N) while rice husk biochar was most effective for field water holding capacity.

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Abstrak

Penggunaan biochar pada kebiasaannya dilaporkan dapat meningkatkan kualiti tanah dan mengurangkan larut lesap nutrien. Dalam kajian ini, biochar yang dihasilkan daripada sekam padi dan tempurung kelapa digunakan dalam penentuan ciri-ciri fiziko-kimia, keupayaannya pada kapasiti mengikat nutrien dan air di dalam tanah. Biochar ini telah dihasilkan dengan menggunakan proses konvensional relau berputar (untuk sekam padi) dan relau kiln (untuk tempurung kelapa). Daripada kajian ini, didapati bahawa biochar tempurung kelapa (BTK) sangat berkesan dalam kapasiti mengikat nitrogen berbanding dengan biochar sekam padi (BSP). Analisis larut lesap untuk tempoh 19 hari (aplikasi 100 ml setiap hari) telah mengenal pasti 15 g/kg BTK berupaya mengurangkan larut lesap N pada kadar kurang daripada 5 mg/liter di tanah jenis siri Bungor berbanding dengan sampel lain. Sementara itu, BSP sangat berkesan untuk mengekalkan kandungan air berbanding dengan BTK dengan pengekalan air tertinggi dicatat pada 31.2%. Keputusan keseluruhan menunjukkan bahawa biochar yang dihasilkan menggunakan kaedah konvensional mempunyai potensi besar untuk mengurangkan larut lesap nutrien dan meningkatkan keupayaan pegangan air di dalam tanah. BTK lebih berkesan untuk mengurangkan larut lesap nutrien, terutamanya nitrogen manakala BSP adalah berkesan untuk meningkatkan keupayaan pegangan air di dalam tanah. Penyelidikan lanjutan diperlukan untuk mengkaji keberkesanan biochar tersebut kepada pengambilan nutrien dan pertumbuhan tanaman.